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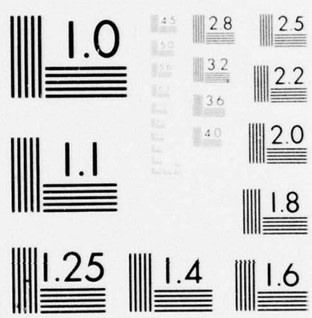

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DYNAMIC RESPONSE OF A SUBMERGED ELASTIC STRUCTURE WITH ELASTIC STRUCTURES ATTACHED TO IT BY INELASTIC SPRINGS

by

F. L. DiMaggio

OFFICE OF NAVAL RESEARCH
CONTRACT NO. N00014-72-C-0119
TECHNICAL NOTE
AUGUST 1977

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ABSTRACT

A procedure is described which may be used to obtain the dynamic response to shock loading of a submerged shell with internal structure attached to it by nonlinear mountings.

A

I INTRODUCTION

In this report, a procedure is described which, when appropriately generalized, may be used to obtain the dynamic response of submerged shells to shock loadings.

For simplicity of presentation, the stiffened submerged shell and bulkheads will be replaced by an elastic beam S, and the attached internal structure, σ, will be discussed as either a (discrete) elastic mass-spring system or a (continuous) elastic beam, all coplanar. σ is attached to S by nonlinear mountings with force-displacement relations denoted by $f_i(\delta_i)$ *), in which i denotes position s_i and δ_i is the relative displacement between S and σ at s_i.

Extension of the equations developed herein to more complicated systems σ and S will be presented in a sequel to this report, Ref. [3].

The effect of surrounding fluid and an incident shock wave introduces additional generalized forces in the equations of motion of S, as discussed in detail in Ref. [1].

*) In what follows, the subscript i of f_i is suppressed when there is only one point of attachment.

II SIMPLE NONLINEAR OSCILLATOR ON ELASTIC BEAM

See Fig. 1:

$$\delta_1 = q_{\sigma 1} - d_S(s_1, t) \tag{1}$$

$$d(s, t) = \sum_i q_{Si}(t)\, \phi_{Si}(s) \tag{2}$$

in which $\phi_{Si}(s)$ are the free-free modes of S, $q_{Si}(t)$ are the corresponding generalized coordinates, and t is time.

The dynamic reaction of σ on S, illustrated in Fig. 2, is equal and opposite to that of S on σ .

The equation of motion (EOM) of σ is, using Eqs. (1) and (2),

$$M_1 \ddot{q}_{\sigma 1} + f(q_{\sigma 1} - \sum_{i=1}^{\nu_S} q_{Si}\, c_{Si1}) = 0 \tag{3}$$

in which

$$c_{Si1} = \phi_{Si}(s_1) \tag{4}$$

and ν_S is the number of modes of S utilized. The EOM of S are

$$\mu_{Sj} \ddot{q}_{Sj} + \kappa_{Sj} q_{Sj} = c_{Sj1}\, f(q_{\sigma 1} - \sum_{i=1}^{\nu_S} q_{Si} c_{Si1}), \quad j = 1, \ldots \nu_S \tag{5}$$

in which

$$\mu_{Sj} = \int_0^L m_S\, \phi_{Sj}^2 ds \tag{6}$$

and

$$\kappa_{Sj} = \mu_{Sj}\, \omega_{Sj}^2 \tag{7}$$

In Eq. (6), $m_S(s)$ is the mass distribution of S and in Eq. (7), the ω_{Sj} are the natural frequencies of S.

Equations (3) and (5) are $\nu_S + 1$ nonlinear ordinary differential equations (ODE) of the second order in the ν_S generalized coordinates of S, q_{Sj}, and the one generalized coordinate, $q_{\sigma 1}$, of σ .

III TWO DEGREE OF FREEDOM ELASTIC SYSTEM ATTACHED BY ONE NONLINEAR SPRING TO AN ELASTIC BEAM

See Fig. 3: Equations (1), (2) and Fig. 2 are still valid, so the EOM of S are again given by Eqs. (5).

A. Non-Modal Treatment of σ

EOM for σ (consisting of both masses and both springs) may be obtained by considering free body diagrams of the two masses and using Eqs. (1) and (2)

$$M_2 \ddot{q}_{\sigma 2} + k\,(q_{\sigma 2} - q_{\sigma 1}) = 0 \tag{8}$$

$$M_1 \ddot{q}_{\sigma 1} + f\Big(q_{\sigma 1} - \sum_{i=1}^{\nu_S} c_{Si1}\, q_{Si}\Big) - k(q_{\sigma 2} - q_{\sigma 1}) = 0 \tag{9}$$

Equations (5), (8) and (9) are $\nu_S + 2$ equations [all but Eq. (8) nonlinear] in the ν_S generalized coordinates q_{Si} and the two coordinates $q_{\sigma 1}$ and $q_{\sigma 2}$.

B. Modal Analysis

See Fig. 4: Equations (1), (2) and (5) still hold. σ now consists of the two masses and the elastic spring connecting them. Let $\underline{a}_{\sigma i}$, i = 1, 2, be the free-free modal vectors of σ (including one rigid body translational mode), ω_i be the corresponding natural frequencies (with $\omega_1 = 0$), and $\underline{M}_{\sigma}$ be the mass matrix

$$\underline{M}_{\sigma} = \begin{bmatrix} M_1 & 0 \\ 0 & M_2 \end{bmatrix} \tag{10}$$

Further, let

$$\underline{A}_{\sigma} = [a_{\sigma 1} \ , \ a_{\sigma 2}] \tag{11}$$

be the principal mode matrix for σ,

$$\underline{p}_\sigma = \underline{A}_\sigma \, \underline{q}_\sigma \tag{12}$$

in which

$$\underline{q}_\sigma = \begin{bmatrix} q_{\sigma 1} \\ q_{\sigma 2} \end{bmatrix} \tag{13}$$

and

$$\underline{F}_\sigma = \tilde{\underline{A}}_\sigma \, \underline{Q}_\sigma \tag{14}$$

where ~ denotes a transpose and

$$\underline{Q}_\sigma = \begin{bmatrix} -f(\delta_1) \\ 0 \end{bmatrix} = \begin{bmatrix} -f(q_{\sigma 1} - \sum_{i=1}^{\nu_S} c_{Si1} q_{Si}) \\ 0 \end{bmatrix} \tag{15}$$

The EOM of σ may now be written as

$$\underline{\mu}_\sigma \, \ddot{\underline{p}}_\sigma + \underline{\kappa}_\sigma \, \underline{p}_\sigma = \underline{F}_\sigma \tag{16}$$

in which

$$\underline{\kappa}_\sigma = \begin{bmatrix} \mu_1 \omega_1^2 & 0 \\ 0 & \mu_2 \omega_2^2 \end{bmatrix} \tag{17}$$

and $\underline{\mu}_\sigma$ is a 2 by 2 diagonal matrix given by

$$\underline{\mu}_\sigma = \tilde{\underline{A}}_\sigma \, \underline{M}_\sigma \, \underline{A}_\sigma \tag{18}$$

Equations (5) and (16) are $\nu_S + 2$ equations in the ν_S normal coordinates q_{Si} and the two normal coordinates $p_{\sigma i}$.

IV ELASTIC BEAM ON AN ELASTIC BEAM

See Fig. 5: The displacements of S and σ may be expressed, respectively, as

$$d_S(s, t) = \sum_{i=1}^{\nu_S} q_{Si}(t)\ \phi_{Si}(s) \tag{19}$$

and

$$d_\sigma(s, t) = \sum_{j=1}^{\nu_\sigma} q_{\sigma j}(t)\ \phi_{\sigma j}(s) \tag{20}$$

in which ϕ_{Si} and $\phi_{\sigma j}$ are the free-free principal modes of S and σ, respectively, q_{Si} and $q_{\sigma j}$ are the corresponding generalized coordinates, and ν_S and ν_σ are the number of modes of S and σ used in the truncated series.

The shortenings of the nonlinear springs are then written as

$$\delta_1(t) = d_S(s_1,t) - d_\sigma(s_1,t) = \sum_{i=1}^{\nu_S} q_{Si}(t)\ \phi_{Si}(s_1) - \sum_{j=1}^{\nu_\sigma} q_{\sigma j}(t)\ \phi_{\sigma j}(s_1)$$

$$= \sum_{i=1}^{\nu_S} q_{Si}\ c_{Si1} - \sum_{j=1}^{\nu_\sigma} q_{\sigma j}\ c_{\sigma j1} \tag{21}$$

$$\delta_2 = \sum_{i=1}^{\nu_S} q_{Si}\ c_{Si2} - \sum_{j=1}^{\nu_\sigma} q_{\sigma j}\ c_{\sigma j2} \tag{22}$$

in which

$$c_{\sigma ji} = \phi_{\sigma j}(s_i)\ , \quad i = 1, 2 \tag{23}$$

The dynamic reactions of σ on S and vice versa are illustrated in Fig. 6. It follows that the EOM of S and σ are

$$\mu_{Si}\ddot{q}_{Si} + \kappa_{Si}q_{Si} = f_1(\delta_1)c_{Si1} + f_2(\delta_2)c_{Si2} \tag{24}$$

$$\mu_{\sigma j}\ddot{q}_{\sigma j} + \kappa_{\sigma j}q_{\sigma j} = -f_1(\delta_1)c_{\sigma j1} - f_2(\delta_2)c_{\sigma j2} \tag{25}$$

in which δ_1 and δ_2 are given by Eqs. (21) and (22). Equations (24) and (25) are a set of $\nu_S + \nu_\sigma$ coupled second order ordinary nonlinear differential equations in the same number of generalized coordinates q_{Si} and $q_{\sigma j}$, $i = 1 \rightarrow \nu_S$, $j = 1 \rightarrow \nu_\sigma$

V CONCLUDING REMARKS

In Ref. [2], the procedure outlined in Ref. [1] and described in detail for particular attachments σ, is generalized for arbitrary internal structures. Similarly, the equations and examples exhibited in the present report will appear as special cases in Ref. [3].

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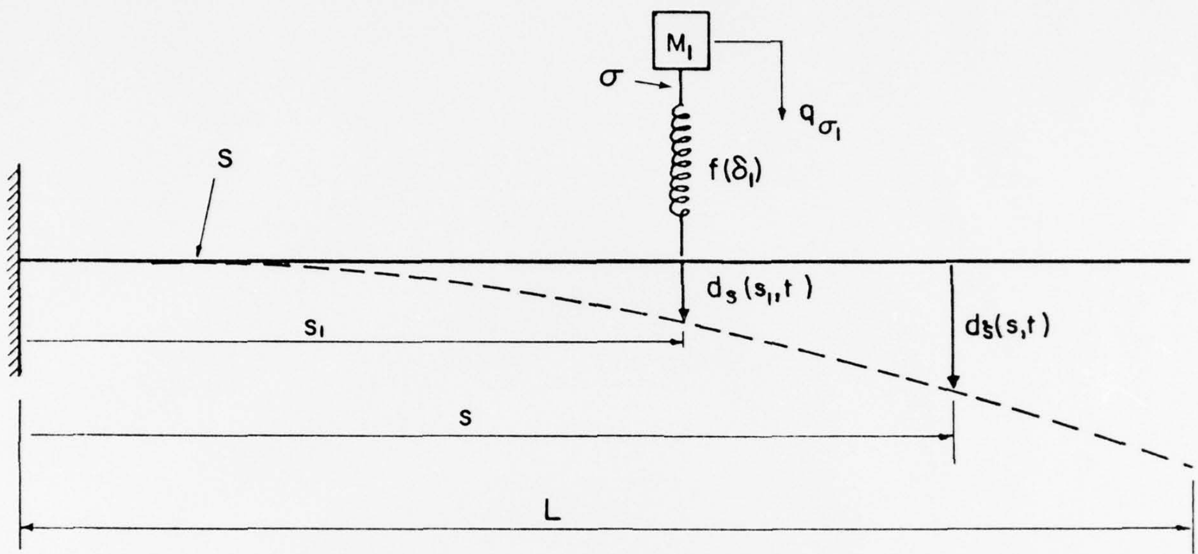

M$_1$
σ
q_{σ_1}
S
$f(\delta_1)$
$d_S(s_1,t)$
s_1
$d_S(s,t)$
s
L

FIG. 1

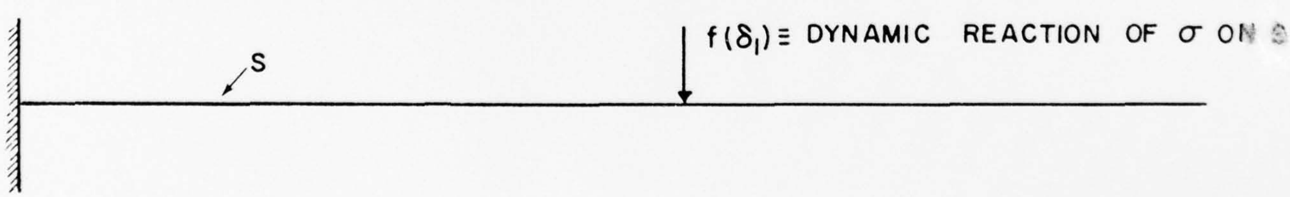

$f(\delta_1) \equiv$ DYNAMIC REACTION OF σ ON S
S

FIG. 2

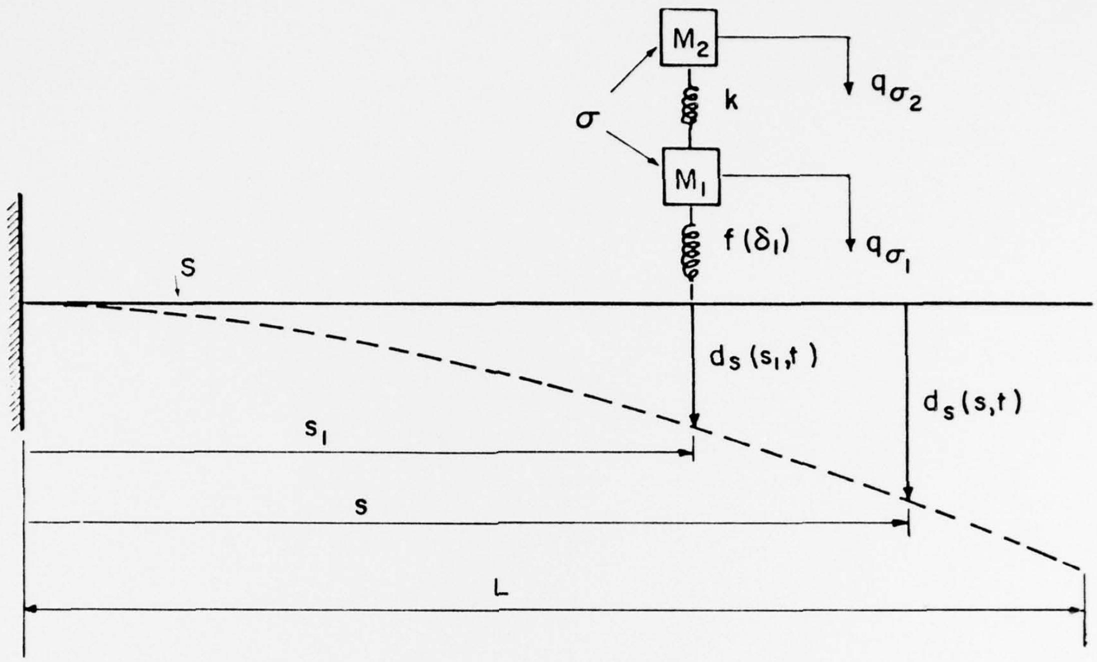


FIG. 3

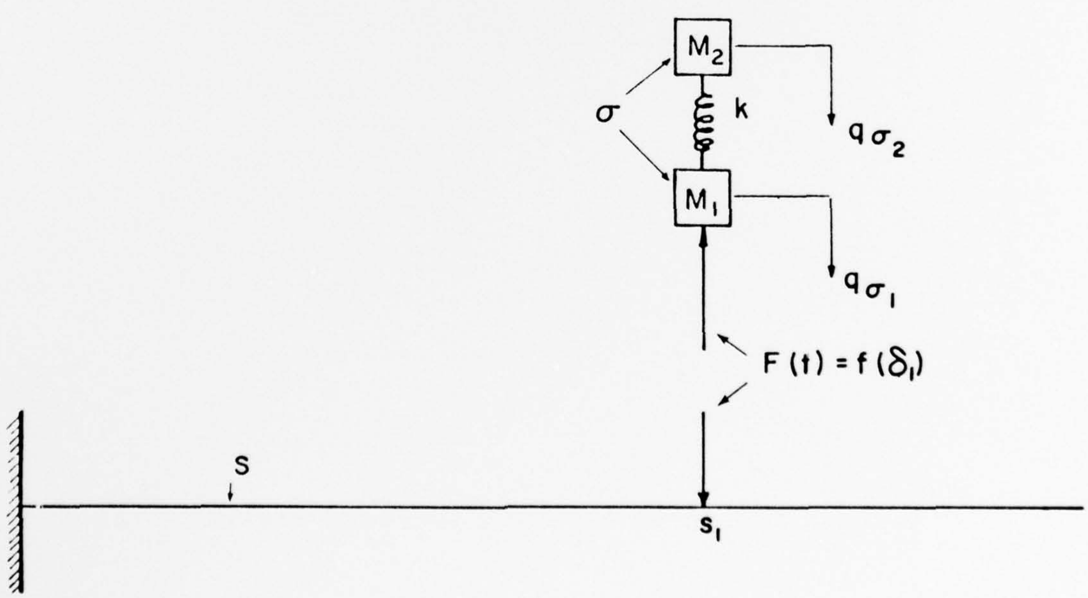
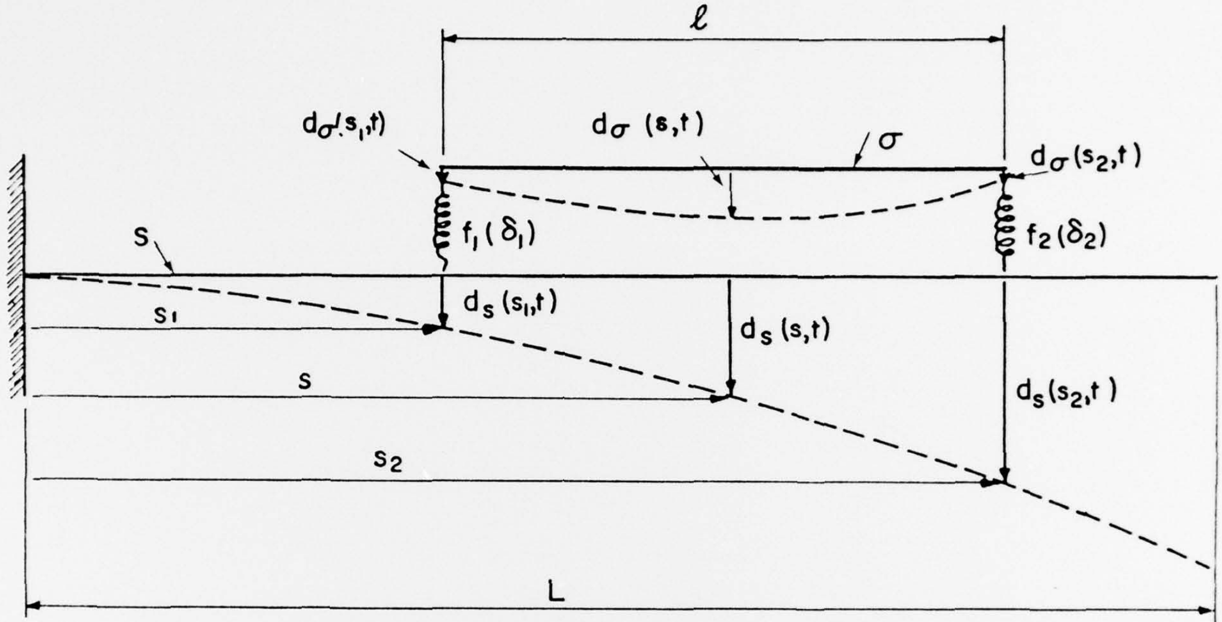
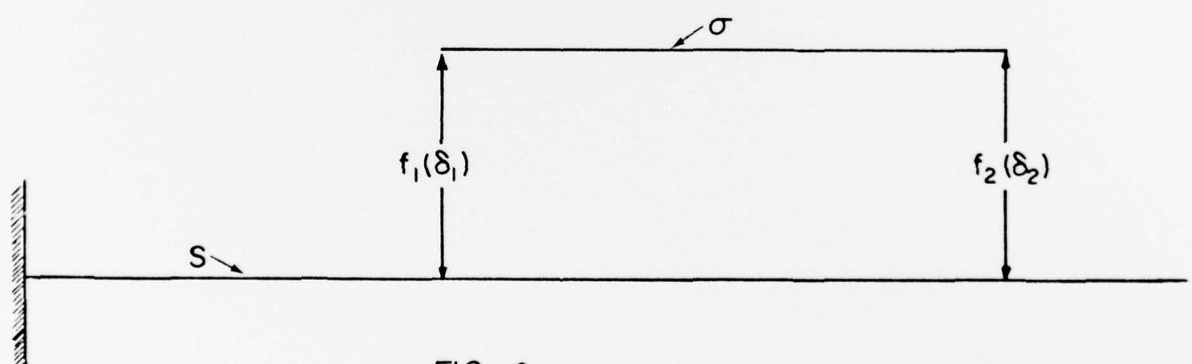


FIG. 4



ℓ
$d_\sigma(s_1,t)$
$d_\sigma(s,t)$
σ
$d_\sigma(s_2,t)$
S
$f_1(\delta_1)$
$f_2(\delta_2)$
$d_s(s_1,t)$
s_1
$d_s(s,t)$
s
$d_s(s_2,t)$
s_2
L

FIG. 5



σ
$f_1(\delta_1)$
$f_2(\delta_2)$
S

FIG. 6

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Submerged Shell

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A procedure is described which may be used to obtain the dynamic response to shock loading of a submerged shell with internal structure attached to it by nonlinear mountings.

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